
Engineering an E-Waste PPG Heart-Rate Monitor

A Technical Report on Photoplethysmography, E-Waste Reuse, and
Prototype Development

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Independent Technical Design Report

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Abstract

This project aimed to respond to two problems found in modern work and study environments: the growth of electronic waste and the separation of users from their natural biological rhythms. A tabletop photoplethysmographic (PPG) heart-rate monitor was engineered from discarded and unused components, including a Raspberry Pi 3B+, LCD screen, webcam module, power bank, SD card, cabling, case parts, and a silicone finger mesh. The device used a dedicated LED and camera to detect small changes in reflected light from the finger. A Python program processed these changes, calculated beats per minute, and displayed a live cardiovascular waveform through Pygame.

Development was divided into concurrent software, hardware, and documentation workflows. Three internal chassis versions and two housing versions were produced. Changes were made after cable tension twisted the internal components, printed supports snapped or blocked ports, the camera sat at the wrong height, an LED shut off under bright light, and movement created unstable readings. The final design used a six-pillar chassis, a removable lid, a flexible finger interface, and a Voronoi-textured enclosure. Five preliminary comparisons were completed against a commercial fingertip pulse oximeter. The prototype remained within one beat per minute of the reference readings under the stationary conditions tested. The result was a functioning PPG heart-rate monitor made mainly from reclaimed components.

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1 Introduction

1.1 Statement of need

Modern designers face two global challenges that can be seen especially in stressful work and study environments. This project aimed to respond to both.

The rapid growth of technology in the twenty-first century has led to massive amounts of obsolescence, as technology can dwarf the capabilities of its predecessors within only half a decade. This has also led to a massive influx of e-waste, with functioning microprocessors and plastics ending up in landfill. In 2022, approximately 62 million tonnes of e-waste were generated globally, while only 22.3% was documented as formally collected and recycled (Baldé et al., 2024). Unsafe dumping and processing can release substances such as lead and mercury into the environment (World Health Organization, 2024).

Modern study and workplace environments can also separate individuals from their natural biological rhythms. Prolonged screen time and stressful academic or work tasks can lead to digital fatigue (Kaur et al., 2022). The project aimed to make a biological process visible within a work or study environment.

1.2 The proposed solution

To solve both problems simultaneously, a tabletop PPG heart-rate monitor was engineered from electronic waste. It was designed as a fast and ergonomic biofeedback tool for stressful environments.

The environmental part of the project was called the “Revive” element. The device diverted a discarded Raspberry Pi, salvaged power bank, reused storage, cabling, and other components from landfill to create the physical device and give them a second life. The psychological part was called the “Thrive” element. Photoplethysmography was used to provide real-time cardiovascular feedback in the form of a heartbeat visualisation.

The prototype measured heart rate, but it did not estimate blood oxygen saturation. A pulse oximeter estimates oxygen saturation as well as pulse rate (U.S. Food and Drug Administration, 2025). For this reason, the device is described in this report as a PPG heart-rate monitor. It was a design prototype and was not intended for diagnosis.

2 Project Planning and Material Sourcing

2.1 Project management and concurrency

The development was structured into three concurrent workflows over ten weeks to make sure the project was completed on time and met its technical requirements. Track A handled software and biophilia. It involved programming the PPG algorithm for heart-rate sensing, configuring the headless Secure Shell (SSH) network so that a laptop could interact with the on-board computer, and designing the user interface. Track B handled hardware and upcycling. It involved sourcing e-waste as hardware for the algorithm, CAD modelling the internal chassis, and engineering the physical enclosure. Track C handled the design folio, feedback, formatting, ongoing evaluation, and progress toward the submission deadline.

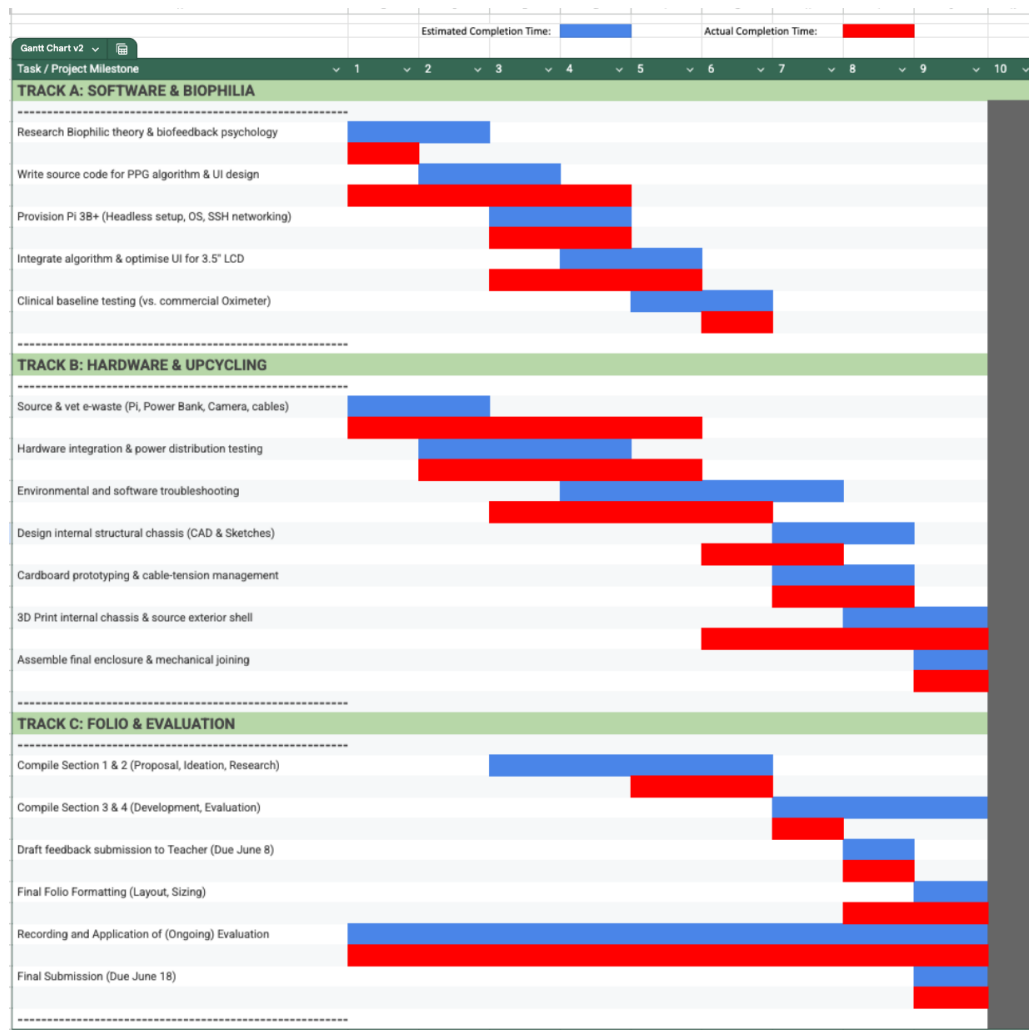


Figure 1. The project Gantt chart, organised into concurrent software, hardware, and documentation workflows.

Note. Created by the author.

Using parallel workflows was required for a project of this complexity and was more efficient than using a single linear timeline. The three tracks allowed work to pivot whenever setbacks happened without halting progress on the other parts of the project. This was especially useful when failures occurred during 3D printing, as software and documentation could continue while another print was prepared.

2.2 Material sourcing

The materials were sourced from old dusty boxes in a garage and from items buried inside drawers. They were items that would have eventually gone to the trash, but were instead given a new life. The major components were:

- **Raspberry Pi 3B+ (1 GB RAM):** discarded and obsolete. Exposed GPIO pins and solder points presented a sharp-edge hazard.
- **64 GB SD card:** a ten-year-old SD card that was reused.
- **3.5-inch LCD screen for Raspberry Pi:** old, with a broken touch digitiser.
- **USB-A LED light:** reused to provide white light for the sensor.
- **2 MP webcam module:** repurposed with a retuned lens.

- **Micro-USB to USB-A cable:** salvaged and used as a power cable.
- **Silicone finger mesh:** salvaged from an unused asthma puffer spacer and fully sterilised before use.
- **10,050 mAh power bank:** a reclaimed Anker PowerCore+. Its lithium-ion cells presented a fire and puncture risk during disassembly.
- **Raspberry Pi case:** old and flimsy, but secure and ventilated for heat dissipation.

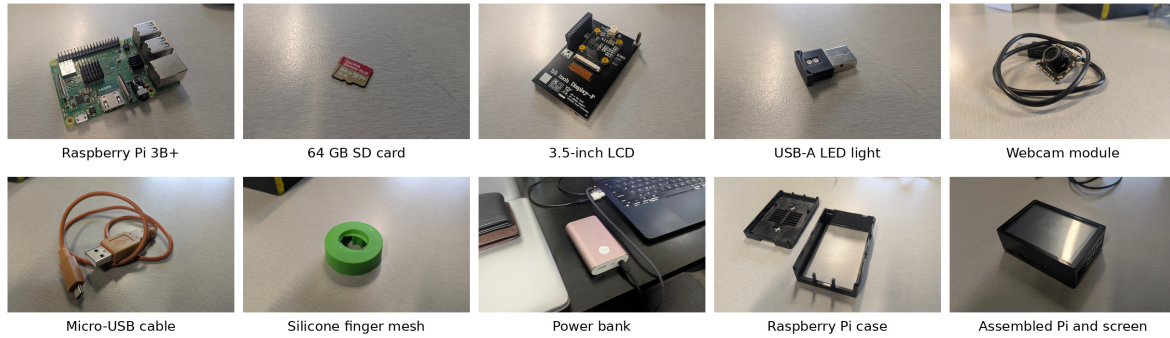


Figure 2. The reclaimed and reused components selected for the prototype.

Note. Photographs by the author.

3 Design Theory and Ideation

3.1 Biophilic design theory

The device used indirect nature to integrate human biology into the workplace, instead of only using superficial biophilic elements such as potted plants or water features. The user could view the rhythm of their own heartbeat in real time. The project was designed around the idea that this physiological biofeedback could ground users in their own natural rhythms. Research on structured heart-rate-variability biofeedback has reported reductions in stress and anxiety, although this effect was not tested with the prototype (Goessl et al., 2017).

Several recognised biophilic design principles were applied. These were based on Stephen Kellert's framework and Terrapin Bright Green's *14 Patterns of Biophilic Design* (Browning et al., 2024). A visual connection with nature was represented by the real-time visualisation of cardiovascular rhythms. Biomorphic forms and patterns were represented by the Voronoi cellular geometry in the enclosure. Indirect nature was represented by the abstraction of a biological system through the user's own heartbeat.

The final 3D-printed enclosure had organic Voronoi and cellular patterns printed directly into its walls. These patterns mimicked natural geometries and broke up the harsh synthetic aesthetic of a traditional desk environment. The pattern was part of the housing itself and was not added as a separate decorative layer.

3.2 The science of photoplethysmography

The device relied on optical physics. As the heart beats, blood volume in the finger's capillaries increases. Because haemoglobin absorbs light, more blood means less light is reflected back to the camera. The dedicated LED illuminated the finger, while the camera captured these small fluctuations

in reflected light at a high frame rate. Photoplethysmography uses these pulse-related optical changes to produce a waveform (Allen, 2007; Park et al., 2022).

Understanding the underlying biophysics of PPG was an incredibly important part of writing the processing code. The camera, LED intensity, finger stabilisation, and software had to work in unison to produce clean raw data.

3.3 Software ideation and logical flow

The logical flow of the photoplethysmography algorithm was mapped out in an engineering notebook before any code was written. Mapping the logic first allowed the coding phase to be structured and efficient. A physical biological function, blood pumping through a finger, needed to be translated into digital data.

A sequence was designed in which the camera captured a continuous video feed. The algorithm isolated the red channel of the pixels, calculated the average brightness per frame, and plotted the peaks. Pulse-related drops in brightness were used to identify a heartbeat.

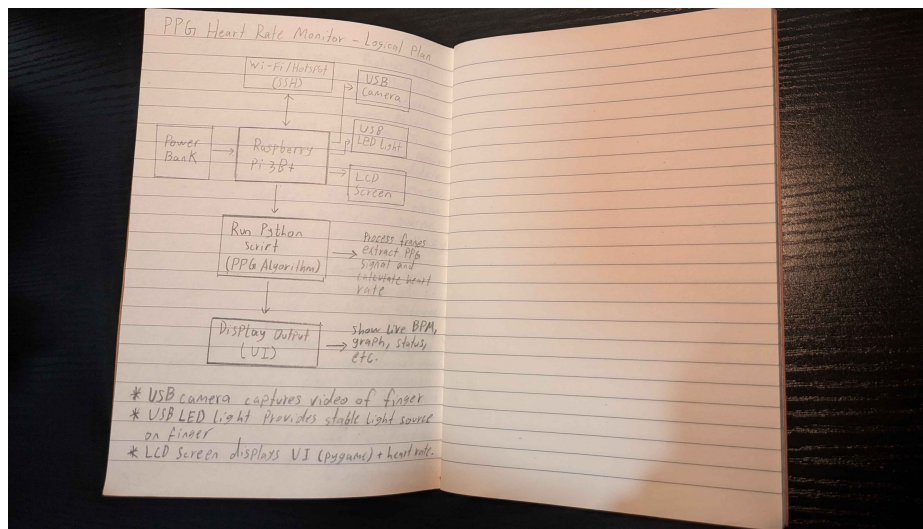


Figure 3. The hand-drawn system architecture and PPG algorithm flowchart prepared before coding.

Note. Photograph and diagram by the author.

Drafting the flowchart provided a clear logical framework to debug against. The relationship between the physical camera input and red-channel isolation had already been mapped, which helped to minimise systematic errors during coding. This also provided practice in visualising system architecture and designing sequences before programming.

4 Software Engineering

4.1 Python and OpenCV pipeline

After the materials had been collected, the logical flowchart was reviewed and the software was developed using Python. The OpenCV computer-vision library was used to capture and process the raw video feed. The pipeline contained five main steps:

1. The Python script used OpenCV to read the video feed from the upcycled camera and capture the raw data for processing.

2. The algorithm isolated the red colour channel and calculated the average pixel intensity. Red produced the clearest usable signal for the program in this camera and lighting setup. The performance of different PPG wavelengths depends on the optical arrangement (Maeda et al., 2011; Park et al., 2022).
3. The script detected peaks and troughs in brightness as the pixel intensity dropped with a pulse of blood.
4. The algorithm logged a peak, measured the time between peaks as an inter-beat interval, and calculated beats per minute.
5. The data were pushed into a user interface rendered with Pygame, which dynamically drew the cardiovascular waveform on the 3.5-inch LCD.

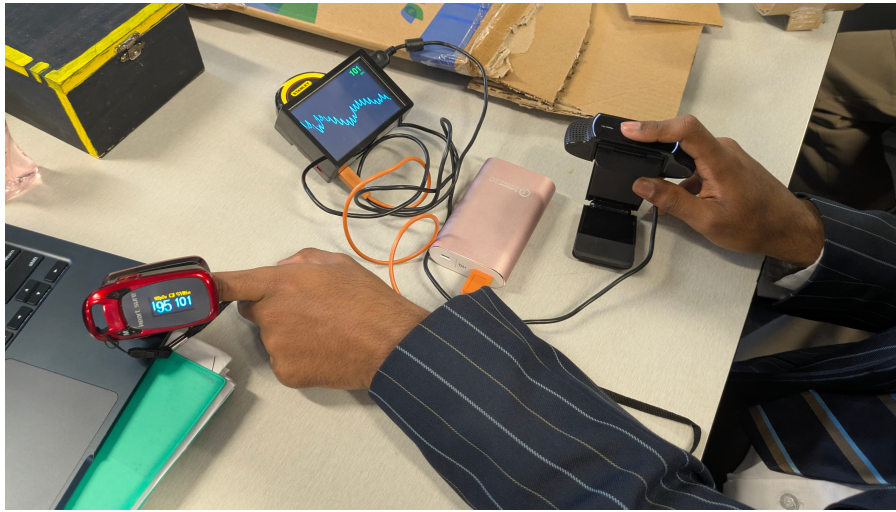


Figure 4. The PPG hardware during testing alongside a commercial fingertip pulse oximeter.

Note. Photograph by the author.



Figure 5. The repurposed webcam module used to capture light-intensity changes from the finger.

Note. Photograph by the author.

4.2 Coding and Raspberry Pi integration

The algorithm was integrated into the Raspberry Pi during Week 4 of development. Fine-tuning was needed to make sure it ran smoothly on the outdated hardware. During Week 5, the first formal test of the algorithm was conducted on the Raspberry Pi in an isolated environment. The room lights were

turned off, and the prototype used its own light source and camera. Commands were sent from a laptop to the on-board computer through SSH.

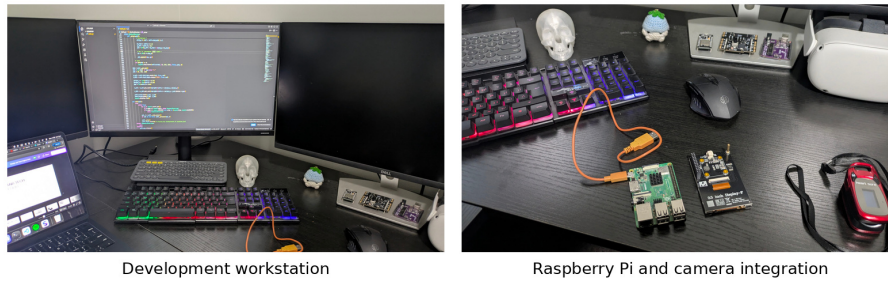


Figure 6. The Week 4 software-development workstation and Raspberry Pi/camera integration setup.

Note. Photographs by the author.



Figure 7. The first formal isolated test of the algorithm running on the Raspberry Pi.

Note. Photograph by the author.

The central code was responsible for the heart-rate measurement. The `_read_sensor()` function extracted the raw pulse signal from the camera by measuring changes in light intensity. The `_process()` function converted this raw data into heart-rate information through filtering and peak detection.

```

99     def _read_sensor(self):
100         ok, frame = self.cap.read()
101         if not ok or frame is None: return None, None
102
103         t = time.perf_counter()
104         h, w = frame.shape[:2]
105         cx, cy = w // 2, h // 2
106         half = self.roi_size // 2
107         roi = frame[cy-half:cy+half, cx-half:cx+half]
108
109         # red channel is best for PPG
110         return float(np.mean(roi[:, :, 2])), t
111
112     def _process(self, val, t):
113         # detrend (aka kill light variance)
114         trend = self.ma1.push(val)
115         detr = val - trend
116
117         # smooth
118         alpha = 0.25
119         if self.last_filt is None: filt = detr
120         else: filt = alpha * detr + (1 - alpha) * self.last_filt
121         self.last_filt = filt
122
123         # peak detector
124         self.std2s.push(filt)
125         thr = 0.6 * self.std2s.std()
126
127         if self.prev_val is not None:
128             deriv = filt - self.prev_val
129             if self.prev_deriv is not None:
130                 ok_refrac = (self.last_peak_t is None) or ((t - self.last_peak_t) * 1000.0 > 330.0)
131                 if self.prev_deriv > 0 and deriv <= 0 and abs(self.prev_val) > thr and ok_refrac:
132                     if self.last_peak_t is not None:
133                         rr = (t - self.last_peak_t) * 1000.0
134                         if 300.0 <= rr <= 2000.0: self.rr_ms.append(rr)
135                     self.last_peak_t = t
136                 self.prev_deriv = deriv
137             self.prev_val = filt
138
139         self.sig.append(filt)
140         self.sample_idx += 1
141

```

Figure 8. The `_read_sensor()` and `_process()` sections of the Python PPG algorithm.

Note. Code and screenshot by the author.

During initial testing, the raw pixel data contained small fluctuations from slight finger movements and the cheaper camera module. These fluctuations caused jumping BPM readings. A baseline threshold system, filtering, and a rolling average were added to stabilise the output. Motion artefacts are a recognised problem in PPG signals (Ismail et al., 2021; Park et al., 2022).

5 Mechanical and Enclosure Development

5.1 Mechanical constraint and initial chassis concept

During the first hardware-integration tests, a serious mechanical flaw was found. The thick salvaged orange USB cable created very high physical tension. When left loose, this tension twisted the Raspberry Pi and power bank, misaligning them with the future housing and potentially damaging GPIO pins or snapping other USB cables.

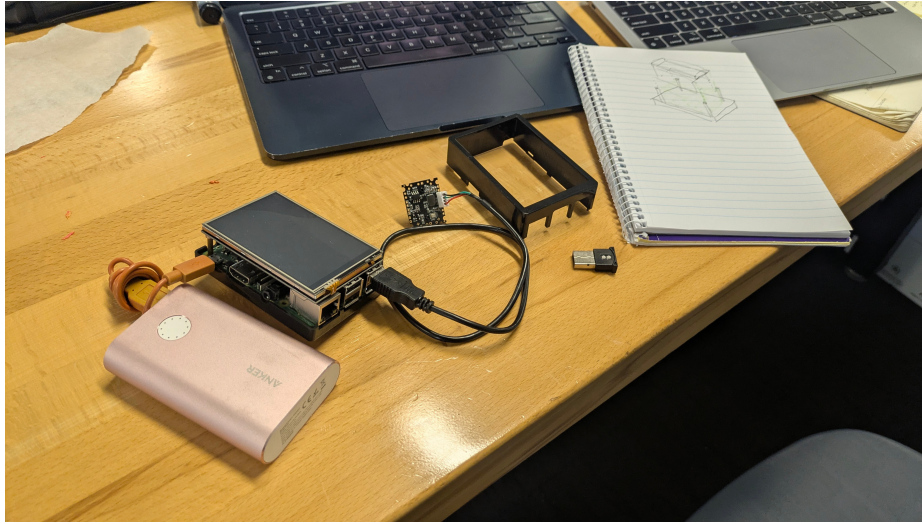


Figure 9. The early hardware arrangement, showing the thick orange USB cable and unrestrained components.

Note. Photograph by the author.

An internal skeleton or chassis was ideated to lock the components together. The initial four-pillar platform acted as an anchoring base for the internal components. The power bank sat underneath and provided a low centre of gravity, while the Raspberry Pi sat above it between the pillars. This arrangement was intended to nullify the shear stress from the cable and keep the electronics stable and aligned with the final housing.

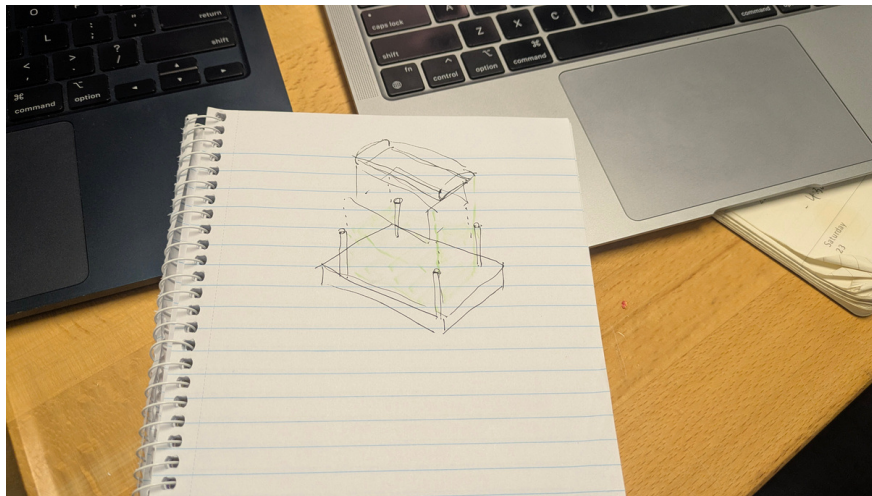


Figure 10. The initial four-pillar internal chassis concept sketch.

Note. Photograph and sketch by the author.

The earlier design had ignored the structural tension of the salvaged USB cable. An internal anchoring system was needed to counteract the external force and keep the electronics aligned. This required the physical relationships and cable tension to be visualised in three dimensions.

5.2 Chassis iterations

The first version of the internal chassis was designed using rough ruler measurements and visual estimates. Four small supports were added to hold the components together. After printing, the chassis was too wide, the components could slide around, and the supports were too thin and loosely placed. They broke easily, and their placement blocked the Raspberry Pi power port.

The second version used more accurate measurements and accurately sized digital doubles of the power bank and case. The supports were redesigned with reinforced oblate, or oval, geometries and overlapped into the side walls of the base plate. This increased the surface area for layer adhesion. The version was much closer, but it was still slightly too wide, the supports remained too thin, and another measurement error blocked the power port.

The third and final version was redesigned with six thicker supports. The oblate supports still overlapped the base plate to reduce snapping under shear stress. The extra two support pillars increased stability and were shorter so that they did not block the power port. The chassis was also the correct width, leaving space to wrap and fit loose cables. It was printed with black filament instead of the orange filament used for the earlier prototypes.

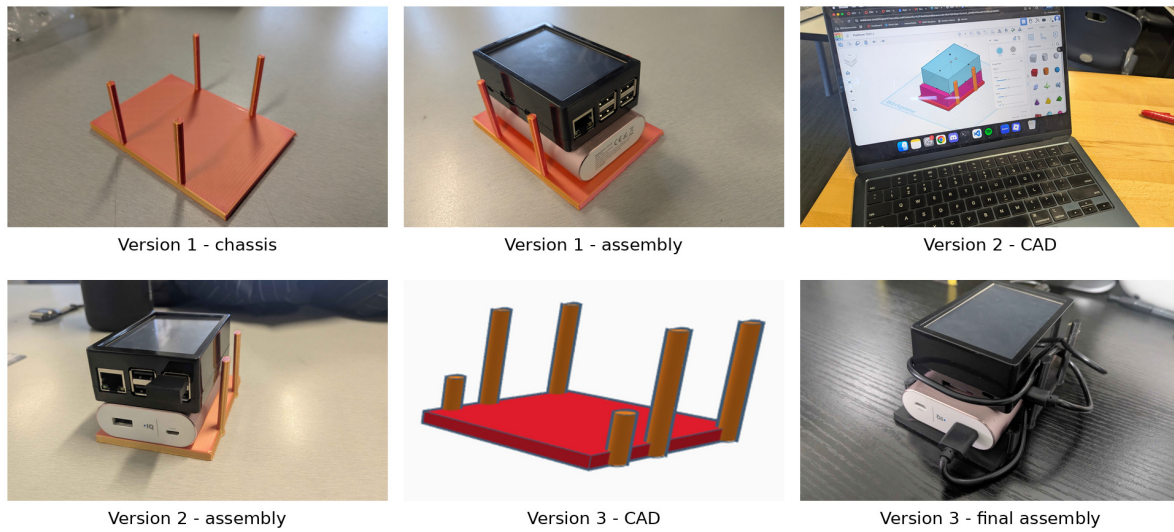


Figure 11. The three chassis iterations, from the first four-pillar prototype to the final six-pillar assembly.

Note. Photographs, CAD models, and diagrams by the author.

The process showed that rough measurements were a bad idea and that more precise measurements were needed for both the housing and chassis. Vertical pillars were vulnerable to snapping under shear stress, while oblate geometry and wall bracing improved layer adhesion. The extra pillars and corrected height clearances resolved both the mechanical stress and port-access problems. Printed PLA has different strengths depending on layer direction, which supported the need to consider orientation and load direction during the redesign (Li et al., 2024).

5.3 Hardware debugging and cable optimisation

The optical USB LED intermittently shut off during testing at school. Environmental testing was conducted by moving the device between dark home environments and sunlit classrooms to test for electromagnetic and ambient-light interference. An ambient-light sensor was discovered on the LED itself. Bright classroom conditions, mainly from open windows, turned the light off, while shadows and covers turned it back on. An electrical-tape blackout patch was placed over the sensor and permanently bypassed the automatic shut-off for the final build.

The debugging at this stage required the first assumptions to be reconsidered and the physical device to be investigated. Upcycled components can contain hidden or undocumented features, so testing under varied environmental conditions was important.

To reduce the remaining mechanical tension on the V3 chassis and components, the thick orange USB power cable was replaced with a more flexible, shorter, black micro-USB cord. This optimised the internal space and improved the internal appearance.



Figure 12. The final internal chassis with the shorter and more flexible black micro-USB cable.

Note. Photograph by the author.

5.4 Enclosure prototyping and ergonomics

A green silicone finger mesh was salvaged from a medical puffer spacer. Before integration, it was sterilised and prepared with isopropyl alcohol. The mesh was selected for three main reasons.

First, the mesh was more comfortable than placing the user's finger into a narrow, solid hole that might not fit every finger. The silicone could bend and encapsulate different finger shapes. Second, it held the finger stable and prevented movement. Excessive movement caused wavering light levels and incorrect BPM readings. Third, the mesh conformed to the finger and blocked most of the external light that could leak into the device and disturb the camera.

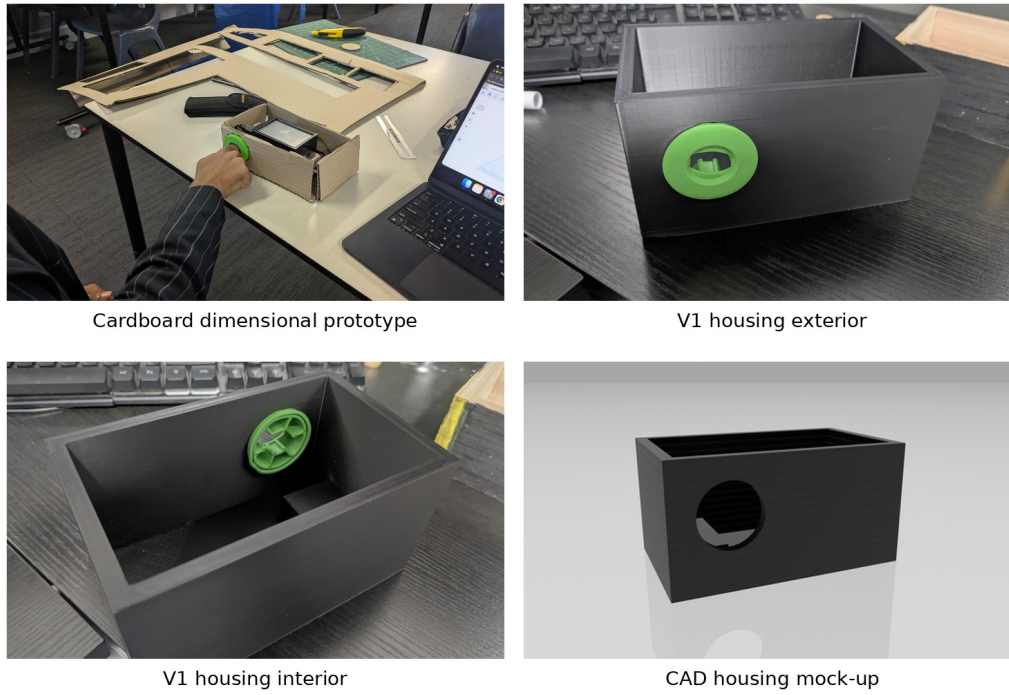


Figure 13. The cardboard dimensional prototype, first printed enclosure, and early CAD housing model.

Note. Photographs and render by the author.

The initial cardboard prototype was a vital part of obtaining the first dimensions and anthropometric measurements. The first printed housing was then tested for structural alignment and ergonomic fit. The V3 chassis and silicone mesh were inserted to test clearances. The housing failed because of a vertical alignment issue, and the mesh opening was too small. The second housing was redesigned with a significantly thicker internal floor that acted as a riser and elevated the camera lens so that it sat flush with the user's finger.

Anthropometrics is the study of human body measurements. The finger entry point needed to comfortably fit almost any user's finger. A rigid hole that was too small could pinch larger fingers and restrict blood flow, making the sensor inaccurate. A hole that was too large could allow ambient light into the device and block the camera from reading the heartbeat. Measurements of the finger, hand length, and hand width were also used so that the housing could be proportioned for the user's hand to rest comfortably on a table (Dianat et al., 2018).

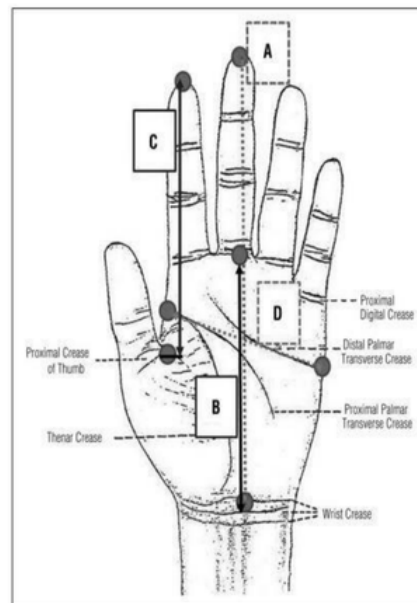


Figure 14. Anthropometric measurements: A, hand length; B, palm length; C, index-finger length; D, hand width.

Note. From *Year 8 Ergonomics & Anthropometrics*, by Hedingham School and Sixth Form, n.d. (Hedingham School and Sixth Form, n.d.).

The mesh was treated as both an ergonomic and optical part of the device. It conformed to different finger shapes, held the finger in place, and reduced light leakage.

5.5 Biophilic manufacturing and CAD housing design

The aesthetic biomimicry part of the biophilic design theory was turned into a practical application through subtractive CAD texturing. In Tinkercad, a biological Voronoi pattern was sourced and scaled parallel to the walls of the V2 housing. It was set to a subtractive, or hole, geometry. By pushing it slightly into the surface, the 3D printer embossed the organic texture directly into the enclosure walls. Specific measurements were used to factor in the strength of PLA and the maximum emboss depth. The cell depth was approximately 3 mm.

The camera seat was measured in coordination with finger anthropometrics to provide a comfortable camera height. Subtractive geometry was used to create a cylindrical finger-mesh window in the front wall. The lid was designed at 120 by 190 mm, with a 1 mm clearance fit for the lip and a 5 mm overhang for lifting. The V3 chassis was also fitted digitally inside the housing and aligned with the camera seat.

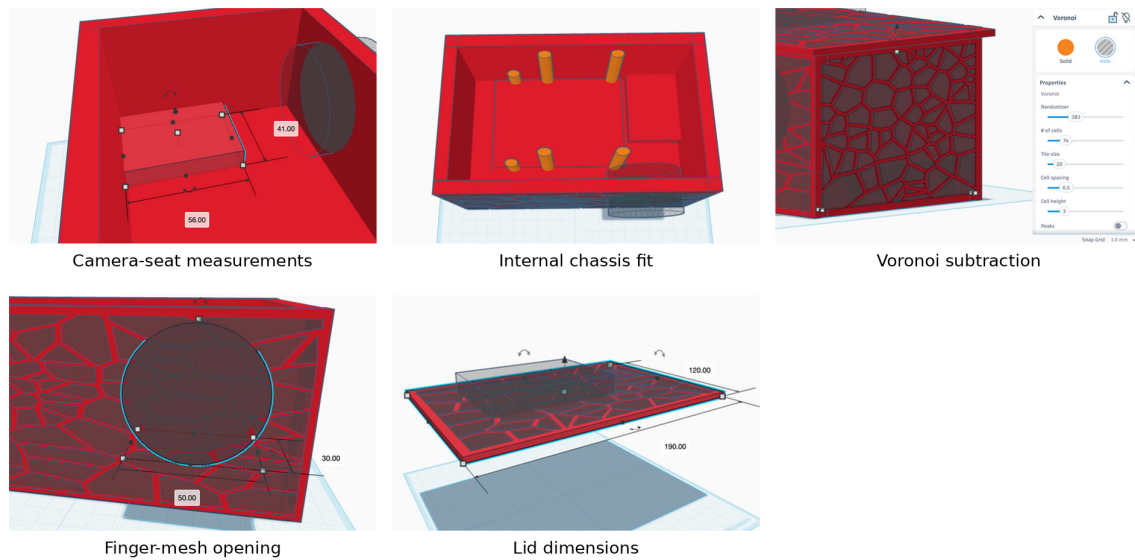


Figure 15. The subtractive CAD process used to create the camera seat, internal fit, Voronoi wall texture, finger opening, and lid.

Note. CAD models and screenshots by the author.

The enclosure could not be a stark grey box if it was to be accepted in work and study environments. Natural organic geometries were used to break up the rigid, box-like feel of the housing. Embossing the Voronoi pattern directly into the CAD model also provided practice in subtractive modelling.



Figure 16. A Blender render showing the device at the centre of a work or study desk.

Note. Render by the author.

5.6 Final assembly and mechanical joining

The second version of the printed housing successfully aligned the internal V3 chassis with the external finger mesh. The Voronoi biophilic pattern printed cleanly and gave the exterior a tactile and organic aesthetic. Masking tape was intentionally used as a quick and effective method of holding down the camera. It was residue-free and easy to remove, which supported the serviceability of the final product.

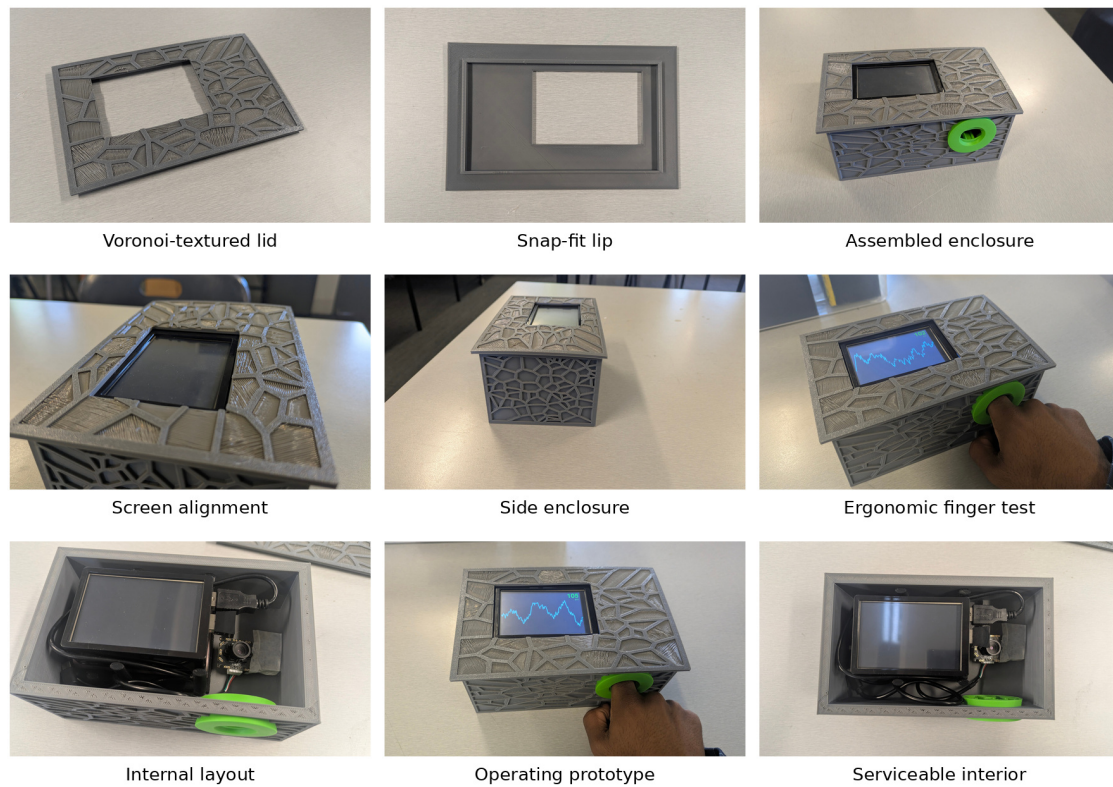


Figure 17. The final assembly, including the textured lid, snap-fit lip, internal layout, display alignment, and ergonomic finger test.

Note. Photographs by the author.

The lid was engineered with an internal snap-fit lip. This secured the device firmly while still allowing future access to the Raspberry Pi and power bank without destroying the housing. The Voronoi texture was printed directly onto the lid.

Mixed joining methods were used for different functional needs. The Raspberry Pi was rigidly secured inside its case using screws. This prevented the board from shifting and protected the GPIO pins and ports from shear stress. The internal screws anchored the Raspberry Pi, while the external snap-fit lid allowed tool-free access to the power bank and SD card. Snap-fit joints in additively manufactured parts require deliberate geometry and consideration of the printing process (Klahn et al., 2016).



Figure 18. The completed enclosure with the screen operating and flexible finger interface in use.

Note. Photograph by the author.

6 Testing and Evaluation

6.1 Preliminary heart-rate comparison

During Week 6 of development, a simultaneous test was conducted against a commercial fingertip pulse oximeter to evaluate the Python PPG algorithm and hardware integration. During the first test, the prototype matched the commercial device with the same BPM count. This was treated as an informal demonstration, so the test was repeated under stable conditions over several hours.

Each test was conducted one hour after the previous test. Trials 1 to 5 were completed from 4:00 p.m. to 9:00 p.m. to include natural variations in heart rate between measurements. Both the commercial pulse oximeter and the prototype were given 45 seconds to stabilise after the finger was placed before the reading was taken.

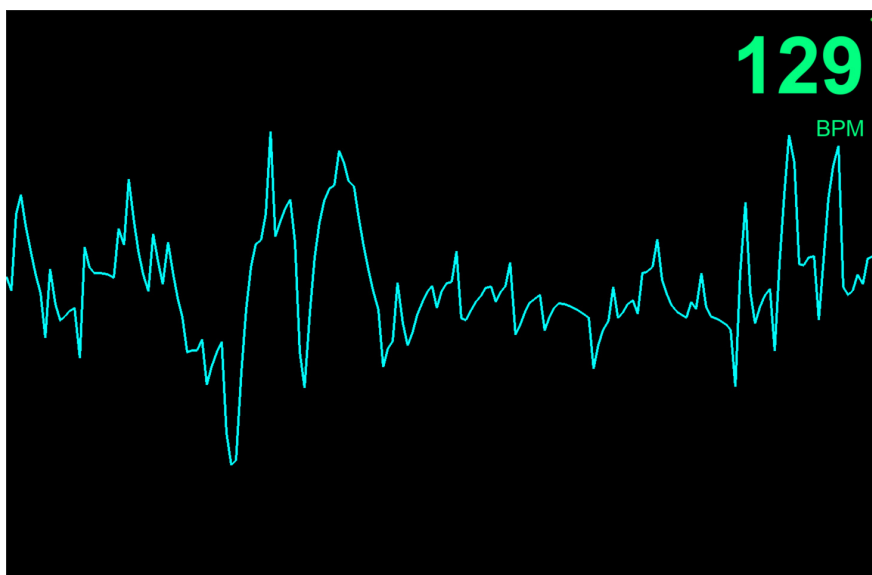


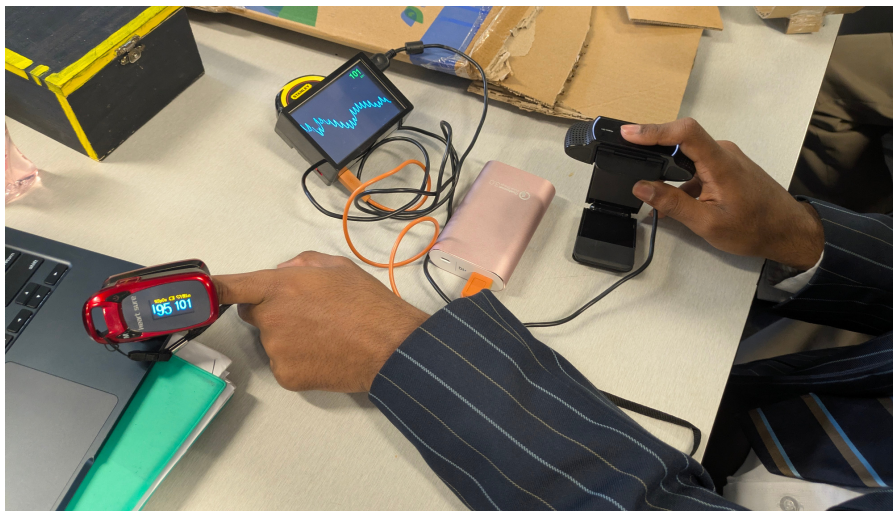
Figure 19. The final heartbeat waveform displayed by the prototype.

Note. Photograph by the author.

Table 1. Preliminary paired heart-rate readings

Trial	Commercial pulse oximeter	Prototype
1	82 BPM	82 BPM
2	78 BPM	79 BPM
3	91 BPM	90 BPM
4	87 BPM	87 BPM
5	76 BPM	77 BPM

Across the five tests, the prototype consistently measured within ± 1 BPM of the commercial pulse oximeter. This showed that the PPG algorithm and hardware configuration could produce closely matching heart-rate measurements under the conditions tested.

**Figure 20.** The prototype and commercial pulse oximeter operating simultaneously during the paired comparison.

Note. Photograph by the author.

The comparison involved one user, five paired readings, stationary conditions, and a commercial pulse oximeter as the reference. It was preliminary proof-of-concept testing and did not establish clinical accuracy or interchangeability. Agreement between measurement methods normally requires a broader set of paired observations and an analysis of the differences between them (Bland & Altman, 1986).

6.2 Life-cycle analysis

A standard life-cycle analysis of a new medical device or microcomputer includes the extraction of materials such as silicon, lithium, copper, and gold. Mining and processing these materials can create environmental impacts. Manufacturing circuit boards, batteries, and plastic housings also uses materials and energy. By upcycling an existing power bank, Raspberry Pi 3B+, webcam module, display, and other locally available parts, the project avoided the manufacture of equivalent new major components for this build. Keeping products and components in use for longer is consistent with circular design strategies (Bocken et al., 2016).

The project exceeded the 80% reclaimed-materials constraint because the main functional components, including the Raspberry Pi, LCD screen, webcam module, power bank, SD card, USB cable, finger mesh, and case components, were salvaged or reused. Only minor joining and finishing

materials were newly introduced. The final housing was printed using PLA. PLA can be produced from renewable plant-based feedstocks, although its environmental performance depends on production and end-of-life conditions, and industrial composting is generally required for controlled breakdown (Fonseca et al., 2023).

At the end of the product's life, the hybrid joining system allowed the device to be dismantled. The Raspberry Pi was secured with screws instead of glue, the lid could be removed, and the electronics could be separated from the printed shell for recycling or reuse.

6.3 Functional and aesthetic evaluation

The device worked reliably during the final tests. The PPG algorithm and camera sensor measured within ± 1 BPM of the commercial device under the tested conditions. The upcycled silicone mesh worked as a finger support and light-reducing seal. The V3 six-pillar chassis reduced the tension from the salvaged cables, and the screw and snap-fit joining system protected the internal GPIO pins while allowing access for servicing.

The 3D-printed Voronoi texture turned the plastic housing from a basic box into a tactile enclosure. The Raspberry Pi, exposed camera board, internal tape, and cabling were hidden inside the custom grey housing. The grey matte finish and organic biomimicry softened the rigid synthetic appearance of a standard desk setup and allowed the device to fit cleanly into a modern workspace.

6.4 Psychological objective and wellbeing

The psychological objective was to bring users back to nature and their biological processes in stressful environments such as study rooms and workplaces. The device displayed the rhythmic pulsing of the user's heartbeat and produced the intended real-time biofeedback loop. The 3D-printed Voronoi cellular texture also softened the rigid synthetic appearance of desktop technology and applied the planned indirect-nature design.

The design aimed to interrupt panic or anxiety cycles by grounding the user in their own biology and to reduce cognitive fatigue through biophilic design. These outcomes were not tested during the project. Structured heart-rate-variability biofeedback can involve paced breathing, beat-to-beat feedback, and a defined training process (Goessl et al., 2017; Lehrer & Gevirtz, 2014). The prototype displayed pulse rate and a waveform, so its effect on wellbeing remains an objective for future testing.

7 Final Reflection and Ongoing Evaluation

The development of this project showed that a linear manufacturing process was rarely successful. Continuous evaluation and pivoting were required, and the process was incredibly mentally demanding.

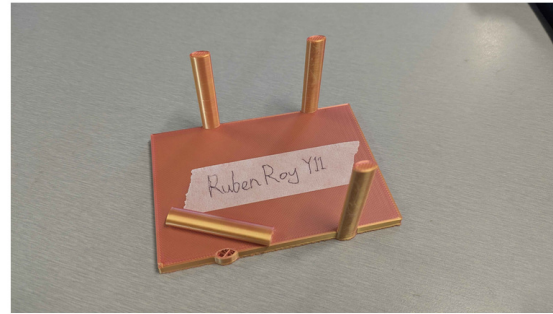
The optical LED failed randomly because of a hidden ambient-light sensor. Environmental debugging and a physical blackout patch were required. This showed that upcycled components can contain hidden or undocumented features and need to be tested under varied environmental conditions.

The initial internal chassis failed under shear stress and poor tolerance. The CAD design was revised twice before the V3 chassis stabilised the hardware. The calculations needed to be precise so that the supports did not block the power port. A single miscalculation could make an entire print unusable. The process also showed that 3D-printed PLA has anisotropic strength properties and must be oriented around the direction of the applied load (Li et al., 2024).

The raw pixel data contained small fluctuations from finger movement and the cheaper camera module, which caused jumping BPM readings. The algorithm was refined with a baseline threshold system, filters, and a rolling average. These changes turned the raw data into more stable readings for the user.



Sensory failure: USB LED



Structural failure: early chassis

Figure 21. Examples of sensory, structural, and software failures encountered during development.

Note. Photographs and screenshots by the author.

These sensory, structural, and software failures were important parts of the building process. They developed the problem-solving, CAD, and signal-processing skills needed to turn the random pile of e-waste into an aesthetic and functioning prototype.

8 Conclusion

A working tabletop PPG heart-rate monitor was produced from obsolete and unused electronic components. The Raspberry Pi, LCD screen, webcam module, power bank, SD card, cables, finger mesh, and case parts were salvaged or reused. Python, OpenCV, and Pygame were used to process the camera feed, calculate BPM, and display a live cardiovascular waveform.

The physical design developed through three chassis versions and two housing versions. Cable tension, blocked ports, weak supports, camera alignment, ambient-light interference, finger movement, and software noise all required evaluation and redesign. The final assembly used a six-pillar chassis, removable joining methods, a silicone finger interface, and a Voronoi-textured enclosure. In five preliminary stationary comparisons, the readings remained within one BPM of a commercial fingertip pulse oximeter.

The project turned a random pile of e-waste into an aesthetic and functioning prototype. This was achieved through planning, coding, CAD modelling, testing, and repeated improvement. The project also exceeded the 80% reclaimed-materials constraint and gave its main electronic components a new life.

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